Recognition of Pictures May Not Require Central Attentional Resources

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Abstract

Carrier and Pashler (1995) concluded that memory retrieval is indeed subject to the central bottleneck. Using locus-of-slack logic in a dual-task paradigm, they reported that memory retrieval on Task 2 was delayed until after central operations on a tone discrimination Task 1 had been completed. Here, we present an experiment that extended Carrier and Pashler's method to memory for pictures rather than words. Our results suggest that recognition of pictures is not subject to central resource limitations, at least when instructions and feedback encourage participants to employ parallel-processing strategies and when preferred stimulus-response modality pairings (visual to manual and auditory to vocal) are used.

Keywords: attention, memory, dual-task, psychological refractory period, recognition, familiarity

Introduction

Sensory systems can process several stimuli in parallel, especially when those stimuli are presented in different modalities (Treisman & Davies, 1973). However, evidence suggests that human cognitive architecture typically does not permit deeper processing for several stimuli at the same time (Pashler, 1984, 1994). One theory holds that many processing stages require capacity-limited central resources that can work on only a single task at any time, resulting in a cognitive processing bottleneck (see Pashler & Johnston, 1998 for a review). It remains controversial whether the processing bottleneck is confined to selecting responses to stimuli (cf. Pashler & Johnston, 1989) or includes stimulus analysis and classification. Bottleneck delays have been reported even with simple go/no go tasks that require minimal response processing (Van Selst & Johnston, submitted), and perceptual classification has been reported to be delayed by the central bottleneck (Johnston & McCann, 2006).

Whether a processing stage is subject to the central bottleneck may depend on whether it is accomplished by cognitive systems specialized to operate autonomously. Processes might bypass the central bottleneck if they depend on specialized circuits at lower levels of the nervous system (including reflexive stimulus-response loops) or when they are highly practiced (Lien, Ruthruff, & Johnston, 2006).

Here, we examine whether memory retrieval processes are blocked by the central bottleneck. Memory retrieval arguably meets the criteria laid out by Lien, Ruthruff, and Johnston (2006): presented with a familiar stimulus, one cannot help but recognize it (Jacoby, 1991); the human brain includes specialized structures dedicated to memory functions (Scoville & Milner, 1957; Squire & Zola-Morgan, 1991); and memory retrieval, as a recurrent component of behavior, is (typically) highly practiced. Thus, it is reasonable to hypothesize that memory retrieval (particularly, recognition: see Jacoby, 1991) might not be subject to the central bottleneck. Two special cases have previously been investigated with different outcomes. The central bottleneck was found to block the implicit memory retrieval required for word identification (McCann, Remington & Van Selst, 2000) but not for letter identification (McCann & Johnston, 1992) perhaps reflecting greater practice for component letters.

The only test of whether an explicit memory task is subject to the central bottleneck was reported by Carrier and Pashler (1995). They tested whether explicit recall and recognition of word list items is subject to the central bottleneck; they concluded that it is. The method used in Carrier and Pashler's (1995) work, and in our experiment, will be discussed in the next section.

Dual-Task Methodology

A common hypothesis in cognitive psychology is that a task can be decomposed into a sequence of discrete processing stages. For example, a tone discrimination task (where participants indicate which of two tones they heard) can be decomposed into a perceptual stage that classifies the tone, a response selection stage that decides what action is to be performed, and a response execution stage that translates the selected response into motor action and executes that action. While there is a consensus that response selection is subject to the central bottleneck, there is less agreement about other stages.

Evidence about the central bottleneck comes mainly from the Psychological Refractory Period (PRP) paradigm, which requires participants to perform two tasks at the same time. This requirement produces delayed response times (RTs) for at least one task, usually the second task. One explanation of this result is shown in Fig. 1, following Pashler & Johnston (1989). Suppose that a tone discrimination task (task 1) and a light discrimination task (task 2) must be performed together. The stimuli for the two tasks are presented in rapid succession at a varying stimulus onset asynchrony (SOA). Each of the tasks is shown decomposed into a perceptual stage not requiring central resources, a response selection stage that does require central resources, and a response execution stage not requiring central resources. At short SOAs, the perceptual stages occur in parallel (see Figure 1). However, task 2 response selection cannot start until the completion of task 1 response selection, resulting in a delay. This delay lengthens task 2 RT at short SOAs (where the task demands overlap in time) relative to long SOAs (where they do not), as shown in Figure 2. The dual-task delay of task 2 responses is commonly called the *Psychological Refractory Period* (PRP) effect.

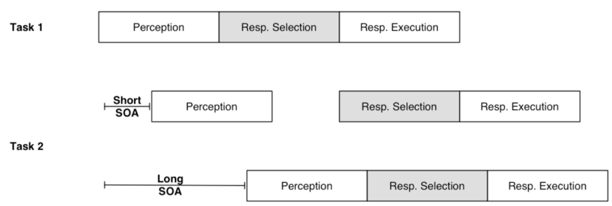

Figure 1. A simple processing stage model shows how the PRP effect results from a delay in response selection on task 2. (White boxes represent information processing stages that do not require central resources; Grey boxes represent stages do require central resources).

The basic dual-task PRP paradigm can be adapted, using the *locus-of-slack method* (McCann & Johnston, 1992), to assess whether a processing stage in task 2 occurs before or after the start of the bottleneck. To use the method, one manipulates the duration of the stage of interest (for instance, in a visual task, the perception stage can be lengthened by reducing stimulus contrast). If we lengthen the duration of a task 2 stage prior to the bottleneck, at short SOAs one expects the added time to occur in parallel with task 1 response selection, and therefore not to lengthen overall task 2 RT (see Figure 3, upper left). However, at long SOAs, the lengthened stage is on the critical path for task 1, so the added time should lengthen task 2 RT (Figure 3, lower left). The disappearance of the effect of Difficulty of Retrieval on task 2 RTs for short SOAs (see Figure 4, left panel) is known as *absorption into cognitive slack*. If we now consider a task 2 difficulty manipulation that lengthens a central stage that occurs at or after the start of the bottleneck, absorption into slack cannot occur at any SOA. Here, the task 2 manipulation will increase task 2 RT by the same amount for all SOAs, producing an additive pattern (See Figure 3, upper and lower right panels and Figure 4, right panel).

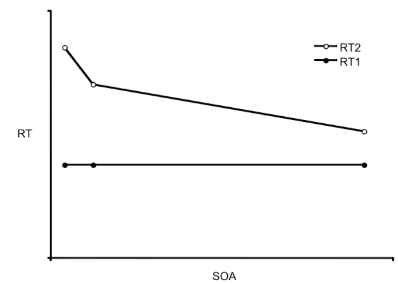

Figure 2. Response time data from a hypothetical dual-task experiment. Responses to task 2 are significantly slower at short SOA than at long SOA.

Thus, by adding time to a particular stage in task 2 and observing whether the added time shows up equally across all SOAs or disappears at the shorter SOAs, we can determine whether that stage occurs before or after the bottleneck onset. This tells us whether the stage requires limited central resources hypothesized to cause the bottleneck.

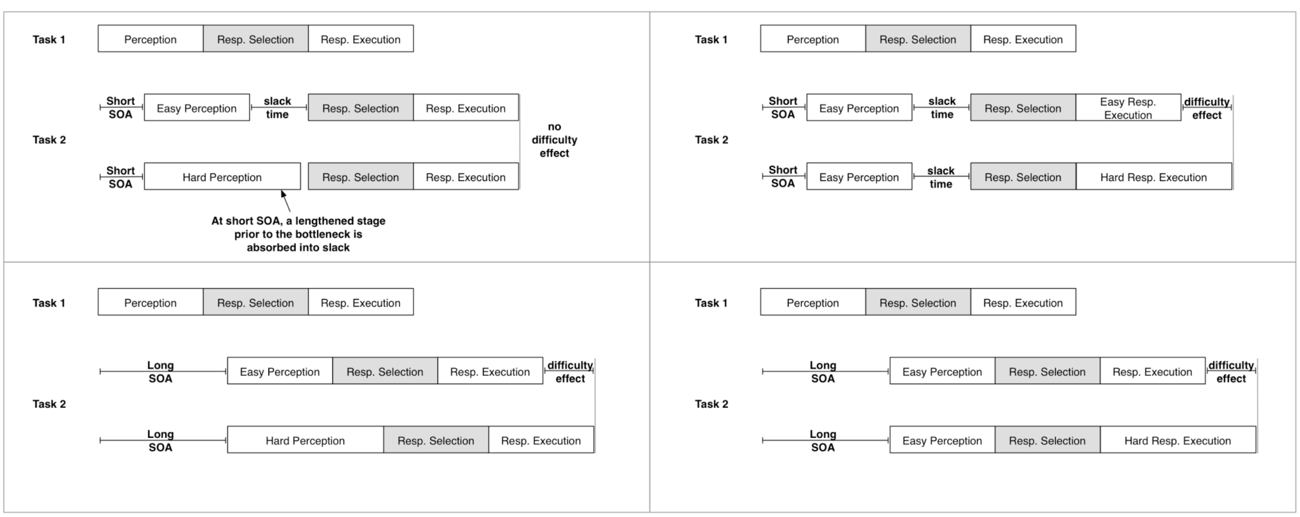

Figure 3. Upper left: At a short SOA, lengthening a processing stage that occurs prior to the bottleneck has little or no effect on task 2 RT. Lower left: At a long SOA, lengthening a processing stage that occurs prior to the bottleneck produces a measurable increase in task 2 RT. Upper right: At a short SOA, lengthening a processing stage that occurs at or after the bottleneck produces a measurable increase in task 2 RT. Lower right: At a long SOA, lengthening a processing stage that occurs at or after the bottleneck produces a measurable increase in task 2 RT.

Memory Retrieval and the Processing Bottleneck

Carrier and Pashler (1995) applied locus-of-slack logic to determine whether memory retrieval requires limited central resources. In their Experiment 2, task 1 required participants to indicate by key press whether an audible tone was high or low. Task 2 required them to indicate by key press whether a printed word appeared on a study list presented shortly prior to the current block of dual-task trials. They manipulated the duration of Task-2 memory retrieval by varying the number of times a word was studied (1 vs. 5). Responses to the memory task were substantially slowed when the stimulus onset asynchrony (SOA) for the two tasks was short (a normal PRP effect). More importantly, the memory task manipulation had an (approximately) equivalent effect at all SOAs, suggesting that memory retrieval required central resources and therefore cannot proceed in parallel with the response selection stage of another task.

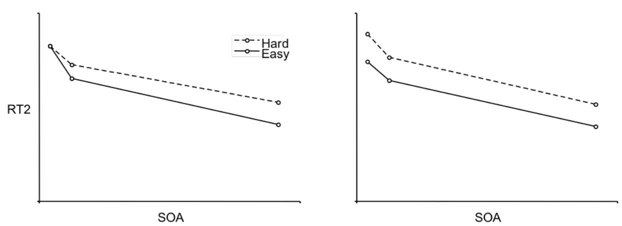

Figure 4. Hypothetical response time data for hard and easy versions of task 2 in a dual-task experiment. Left: pattern expected when a difficult manipulation affects a processing stage prior to the bottleneck. Right: pattern expected when the affected stage occurs at or after the bottleneck.

One limitation of Carrier and Pashler (1995) is that they studied central resource limitations on memory retrieval only for words. Other stimuli (for example, pictures) might be retrieved without being subject to central resource limitations. Our experiment examined this possibility.

The Present Experiment

Carrier and Pashler (1995) noted that their data are at odds with prior work indicating that memory retrieval is not subject to dual-task interference. As those authors point out, Jacoby (1991) provided evidence that familiarity judgments may not be subject to the same central resource limitations that affect conscious recall. To the extent that recognition memory requires assessing familiarity more than it requires recollection of a particular episode, it is surprising that Carrier and Pashler (1995) obtained the result that they did.

One possibility is that methodological details of Carrier and Pashler's method limited their participants' ability to perform memory retrievals concurrently with another task. In a previous study, we replicated Carrier and Pashler's (1995) Experiment 2 with a few other modifications to their method to that should have maximized the possibility that participants would be willing and able to do the two tasks in parallel. Specifically, we used instructions and feedback that emphasized both speed and accuracy. On each of the tasks, we used preferred input-output modality pairings, and we eliminated a possible response modality conflict (Green, Johnston, & Ruthruff, 2005).

While those did suggest that Carrier and Pashler's (1995) methods might have limited their ability to observe parallel processing, the pattern of results was not clearly indicative of absorption into cognitive slack. Here we explore the possibility that memory for different stimuli (pictures) may yield a more definitive result. One reason to believe that picture memory will produce clearer results than word memory is that pictures are more unique to the participants' experience, allowing a purer episodic memory retrieval than memory for comparatively well-studied words. In addition, if participants used any sub-vocalization in doing the tone discrimination task 1, then this might have interfered with linguistic processing of the work memory task 2 stimuli.

Method

Participants 32 participants were either students from local colleges working for course credit, or volunteers working for ten dollars per hour of participation. Eight participants were excluded from analysis because they did not follow instructions or did not meet a criterion accuracy level (70% accurate on both tasks), leaving data from 24 participants to be analyzed.

Materials and Apparatus The experiment was run on PC computers with 22-inch color monitors, standard keyboards, headphones, and cardioid microphones. Each participant sat in a dimly lit, acoustically shielded room at a viewing distance of about 60 cm from the screen.

A fixation cross (presented in black on a white background at the center of the screen) was used to orient the participant before each trial

The picture stimuli were 260 black on white line drawings from Snodgrass and Vanderwort (1980). For each participant, 20 pictures were practice items and 240 were experimental items. Half of the pictures were designated study items (to be studied) and half were designated as lure items (not to be studied). The assignment of individual pictures to these conditions was randomized across participants.

The number task used randomly selected integers ranging from one to 20 (inclusive), presented on the screen in black font. The error signal used for the number task was a 200 ms atonal buzzer sound.

Tones were 200 ms in duration. The high tone was a pure 1000 Hz tone; the low tone was a pure 500 Hz tone. These tones were played at a comfortable and clearly audible volume over the participant's headphones. The error signal used for the tone task was the same buzzer sound used for the number task. During test trials, the stimulus tones were equally divided between high and low pitch tones. High and low tones occurred equally often with studied items and lure items, and equally often at different SOAs.

The error message used in the memory task appeared horizontally centered on the bottom half of the screen in red, bold, capitalized font on a white background. The message read “WRONG” for incorrect responses, “TOO SLOW” for responses that after the task deadline, and “INVALID RESPONSE” when the participant pressed a key that was not a valid response option.

Procedure The experiment included one practice block and six experimental blocks. Each block included a picture study phase, a “buffer” number task, and a test phase. Before the experiment began, participants read written instructions for all phases of the experiment, emphasizing that all responses should be made as quickly and accurately as possible. The instructions for the test trials did not specify a specific response ordering, but did emphasize that each response should be made as soon as possible after the appearance of the associated stimulus.

Each block began with a study phase where participants were presented with a set of 20 different pictures to be remembered for a later test. Half of the pictures were presented a single time during the study phase, and half were presented five times (a total of 60 study trials). As in Carrier and Pashler (1995), the study set was constructed so that the interval between the final study trial for one-study items and five-study items was equated. Study trials began with a fixation cross that remained on the screen for 500 ms. 500 ms after the offset of the fixation cross, a picture appeared on the screen and remained visible for 500 ms. There was a 1000 ms inter-trial interval (ITI) following the offset of the picture.

After the study phase, participants completed 40 trials of a number task wherein they indicated whether a presented integer was odd or even. This task was included to prevent participants from rehearsing memory items between the study phase and test trials. Each trial began with a fixation cross presented for 500 ms. 500 ms after the offset of the fixation cross, an integer was presented. Participants indicated that the integer was odd or even by pressing “1” or “2” on number pad, respectively. For this task, participants were instructed to respond as quickly and accurately as possible. When the participant gave an incorrect response or gave no response within 1500 ms, a short buzzer was played over the headphones to indicate the error. A 500 ms ITI followed each number task trial.

After the number task, the dual-task test phase began. In each block, participants completed 40 PRP trials. In each trial, the participant was required to make two responses: a tone discrimination and a recognition judgment. Each trial began with the presentation of a fixation cross for 500 ms. 500 ms after the offset of the fixation cross, a tone was played over the participant’s headphones. Participants were required to indicate which tone was played as quickly and accurately as possible by saying “high” or “low” aloud into the microphone. If the participant responded incorrectly to the tone, or failed to respond within 1500 ms of the tone onset, a short buzzer was played over the headphones to indicate the error. High and low tones occurred equally often with all combinations of test item and SOA.

Either 50, 150, or 1100 ms after the onset of the tone, a picture appeared on the screen. Participants were required to indicate, as quickly and accurately as possible, whether or not the picture was presented during the study phase. Participants pressed the “Z” key to indicate that the picture was in the studied set, or pressed “M” to indicate that the picture was not in the studied set. If the participant responded incorrectly to the picture, or failed to respond within 2000 ms of the picture onset, a message was displayed on the screen indicating the error. The content of the message was dependent on the nature of the error (see the materials section). After each block, accuracy feedback was provided for both the tone task and the memory task. After a short break, participants pressed a key to initiate the next block.

Results

Mean response times are presented graphically in Figure 5 and means and standard errors are also presented numerically in Table 1. Data were analyzed for correct trials only and we excluded trials on which lure items were used for task 2 (all critical comparisons concern just Old 1 and Old 5 memory items).

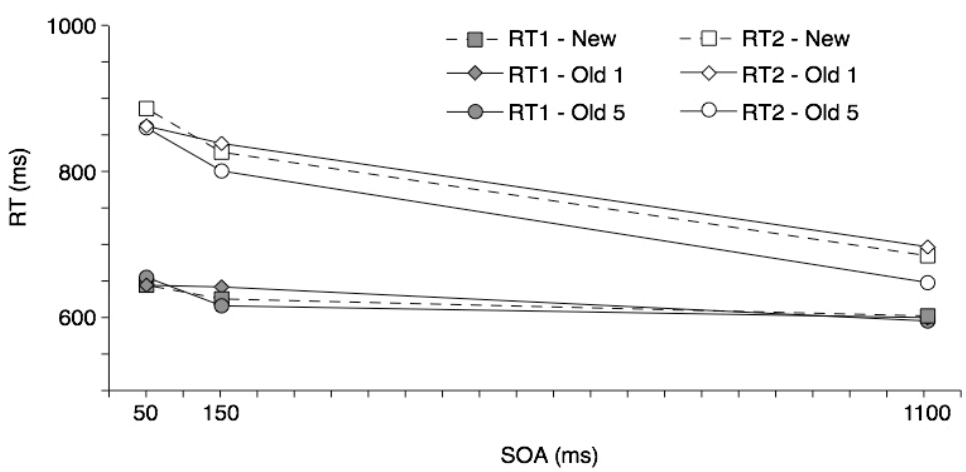

Figure 5. Data from our experiment involving a picture recognition task as task 2.

Table 1. Means and standard errors for response times (ms) on both tasks

		New		Old 1		Old 5	
Task	*SOA*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Task 1							
	50	643 ms	19 ms	643	21	654	24
	150	626	23	645	24	616	19
	1100	599	20	591	21	599	22
Task 2							
	50	885	27	863	32	860	31
	150	821	26	842	30	800	26
	1100	681	13	697	20	647	16

Task 1 (Tone Discrimination Task) There was a main effect of SOA on task 1 RTs, $F(2, 46) = 14.501$, $p < 0.01$. RTs in the 50 ms SOA condition (647 ms) were significantly longer than those in both the 150 ms SOA condition (629 ms) and in the 1100 ms SOA condition (596 ms), $t(24) = 2.02$, $p < 0.05$ one-tailed; $t(24) = 4.94$, $p < 0.05$ one-tailed, respectively. RTs in the 1100 ms SOA condition were also significantly shorter than those in the 150 ms SOA condition, $t(24) = 4.22$, $p < 0.05$ one-tailed. There was no main effect of Difficulty of Retrieval on task 1 RTs, $F(2,23) = 0.262$, $p > 0.50$. There was also an interaction of these factors with respect to task 1 RT, $F(2, 46) = 3.373$, $p < 0.05$.

Task 2 (Picture Recognition Task) Examining RT2 only for studied items revealed a main effect of Difficulty of Retrieval, $F(1,23) = 12.801$, $p < 0.01$, and a significant interaction of SOA and Difficulty of Retrieval, $F(2, 46) = 3.323$, $p < 0.05$. Planned pairwise comparisons examined the difficulty effects in more detail. There was no significant effect of Difficulty of Retrieval on task 2 RT at the 50 ms SOA (the difference between Old 1 and Old 5 items was 3 ms), $t(24) = 0.18$, $p = 0.43$ one-tailed. However, there were significant difficulty effects at the 150 ms SOA (a 42 ms effect), $t(24) = 2.18$, $p < 0.02$ one-tailed, and at the 1100 ms SOA (a 50 ms effect), $t(24) = 6.056$, $p < 0.01$ one-tailed. Further, a planned comparison found Difficulty of Retrieval had a significantly smaller effect at the 50 ms SOA (3 ms) than it did at the 1100 ms SOA (50 ms) , $F(1,95) = 55.04$, $p < 0.001$.

Discussion & Conclusions

Our experiment examined the hypothesis that memory retrieval might not require the central resources responsible for the central bottleneck. Our use of the locus-of-slack method yielded a straightforward answer: The difficulty effect of 50 ms at the longest SOA shrank to only 3 ms at the shortest SOA. At the same time, there was substantial overall PRP effect. Hence, the data show clearly that the memory retrieval task encounters the Central Bottleneck, but only subsequent to the stage at which the difficulty lengthens processing. We see no alternative except the obvious one, that memory retrieval has already returned a result for old items in parallel with task 1 central stages. This is strong evidence that memory retrieval of pictures can proceed without the central resources that cause the Central Bottleneck.

As illustrated in Figure 3, absorption into slack occurs only when the lengthened processing stage comes prior to the point when task 2 requires limited central resources. Thus, our data indicate that memory retrieval does not—at least for the picture memory case we studied—require limited central resources. Because we did find a PRP effect for the picture memory task, we conclude that a stage subsequent to memory retrieval (response selection is the obvious candidate) still required bottleneck resources.

Our results differed from those of Carrier and Pashler (1995), who found no absorption into slack, and thus concluded that memory retrieval is part of the bottleneck. There are three explanations for the different conclusions.

First, it is possible that both conclusions are correct for the retrieval of the different types of material studied. Pictures are surely processed in different brain regions than words and it is plausible that some of these could be more autonomous from central cognition than others.

Secondly, it is possible that some of the methodological changes we made—we thought of them as improvements—were critical. It is possible that if Pashler & Carrier's experiment was repeated with our pairings of input and output modalities, even retrieval from word lists might be found to bypass the central bottleneck (cf. Lien et al, 2006). In addition, if their task involved sub-vocal verbal processing, that could have interfered with processes needed for word memory retrieval. If so, Carrier and Pashler's result could have been caused by a specific resource conflict distinct from the central bottleneck.

Thirdly, the difference between our results and those from Carrier and Pashler (1995) might arise because our participants did not actually recollect the study list episode(s) associated with pictures during dual-task trials, but made fast judgments of familiarity. Carrier and Pashler (1995) anticipated that such cases might occur. This hypothesis is also consistent with Jacoby's (1991) evidence that recollection requires central executive resources while judgments of familiarity do not. Indeed, recent work has demonstrated differences in the neural systems that support remembering an episode and knowing that a stimulus is familiar (Eldridge, et al., 2000). Specifically, remembering (recollecting the specific temporal and spatial context of an episode) is associated with increased activity in the hippocampus, while knowing is not. Given that these processes have (at least somewhat) different neural underpinnings, it would not be surprising if they placed different demands on limited central resources.

Whether our modifications to Carrier and Pashler's (1995) method merely removed a resource conflict that arose because both their tasks required linguistic processing or fundamentally changed the task from one of remembering the study episode(s) to one of judging the familiarity of specific stimuli is an open question. The difference in stimuli might have subtly changed how participants approached their task in our experiment. For instance, our picture stimuli were presumably unique in a particpants' experience allowing a "never seen it" versus "ever seen it" criterion not useful with word lists). A related hypothesis is that activating LTM with a retrieval cue and receiving a general signal whose intensity reflects stimulus familiarity requires no central resources, but that refining the information returned from LTM in order to reconstruct a specific episode does require central resources. We are currently exploring this topic in the lab.

It must not be lost that our data (like those from Carrier & Pashler, 1995) do show an overall delay in responses when a memory task is performed simultaneously with another task. Even when memory retrieval per se is not the source of PRP effects in memory experiments, memory tasks will typically include response selection as a component stage, producing PRP delays whether or not memory retrieval itself is the source of those effects. Clearly, to fully understand the resource requirements of human memory, the methods used here need to be extended to a wider variety of memory tasks, sampling the great diversity of stimuli which human can retrieve from memory. Research to date has barely begun to sample that diversity.

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